THE CO-OPERATIVE UNIVERSITY OF KENYA
CODE: BCSC 4126 NAME: SIMULATION AND MODELING

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WEEK ONE (1) NOTES – FEB – MAY, 2022

Week one (1) Topics: Introduction to Simulation and Modeling: Terminology: system, modeling, simulation, discrete event modeling, time slicing, Monte Carlo, complexity variability.

A TYPICAL SCENARIO- seeing modeling and simulation in context

Consider for that a new airport terminal is to be built. The management may want to make decisions on the following issues:

- The number of check-in desks devoted to each airline;
- The size of the baggage handling system;
- The amount of security check positions;
- The number of departure gates;
- The number of staff to employ;
- The shifts that the employees work.

Solution options: just build the terminal and hope it works; use experience in building other airport terminals; simulate the working of an airport terminal and use information obtained.

Who else simulates?- many companies e.g.

- Manufacturing companies: their production lines;
- Financial services organization- their call centers;
- Transport companies - their delivery networks.

TERMINOLOGY (What ?)

System: a collection of parts organized for some purpose [Coyle, 1996].

Types of systems:

- *Natural systems*: those related to the origins of the universe, e.g. the atom, and the Earth's weather system.
- *Designed physical systems*: those designed and built by the humans e.g. a house, cars and a production facilities.
- *Designed abstract systems*: those that are abstract and designed by humans e.g. mathematics, literature.
- *Human activity systems*: related to human social activity those are consciously, or unconsciously, ordered, e.g. a family, a city and political systems.

Focus: dynamic systems; private and public organizations and operations systems.

Operations systems (operating systems)
Operating systems: a configuration of resources combined for the provision of goods or services [Wild, 2002].

Functions of Operations services: manufacture, transport, supply and service.

Some examples of operations systems that can be simulated:

- An automated production facility or warehouse (a designed physical system);
- A regional health care delivery (a human activity system);
- The service counters, automatic tellers, etc. of a bank (human activity or a social system);
- Mixed physical systems and human activity systems e.g. service operations, banks, call centers, supermarkets, manufacturing plants, supply chains, transport systems, hospital emergency departments and military operations.

Modeling: the process of constructing a conceptual imitation of the real or imaginary system. It may involve the use of formal or modeling languages or mathematics. The output is a model whi ch is a version or a representation of the real or imaginary system.

Simulation (several definitions exist)

- ***Simulation*** is the procedure in which a computer-based mathematical model of physical system is used to perform experiments with that system by generating external stimuli ("demands") and observing how the system reacts to them over a period of time. Simulation is sometimes referred to as *the experimental branch of mathematics.*

- *A simulation* is an imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviours of a selected physical or abstract system (Wikipedia).

- *A computer simulation* (or "sim") is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables, predictions may be made about the behaviour of the system.

- *Simulation* is experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system [Robinson Stewart, 2004].

S*tatic simulation*: imitation of a system at a point in time;
Dynamic simulation: imitation of a system as it progresses through time [Law, Kelton 2000].

Time slicing
This is a way of timing the simulation process by beginning with an original value for time (t_o) and continuously increasing by adding a predefined constant value (Δ_t). In simulation this incremental value should be carefully chosen.

Discrete event modeling
This is a modeling process in which control and most activates are conducted an d directed around the events that take place. The modeling is event driven.

- **Monte Carlo simulation**
  Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. They rely on repeated computation and random or pseudo-random numbers. Monte Carlo methods tend to be used when it is infeasible or impossible to compute an exact result with a deterministic algorithm [Wikipedia]

- *Monte Carlo Simulation* is a statistical technique that involves using a large number of repeated calculations. It is a methodical and formalized version of trial and error. For example Monte Carlo simulation can use historically known interest rate volatilities to scientifically generate the large number of interest rate paths needed to simulate the interest rate sensitivity of bank products with embedded options. [http://www.americanbanker.com/glossary.html?alpha=M]

- *Monte Carlo simulation is a* method that estimates possible outcomes from a set of random variables by simulating a process a large number of times and observing the outcomes. [http://www.bridgefieldgroup.com/bridgefieldgroup/glos6.htm].

- *Monte Carlo simulation* is a method for *iteratively* evaluating a deterministic model using sets of random numbers as inputs. This method is often used when the model is complex, nonlinear, or involves more than just a couple uncertain parameters. A simulation can typically involve *over 10,000 evaluations* of the model. [http://www.vertex42.com/ExcelArticles/mc/MonteCarloSimulation.ht ml].

Basic steps in Monte Carlo Simulation

Step 1: Create a parametric model, $y = f(x_1, x_2, ..., x_q)$.

Step 2: Generate a set of random inputs, $x_{i1}, x_{i2}, ..., x_{iq}$.

Step 3: Evaluate the model and store the results as y_i.

Step 4: Repeat steps 2 and 3 for i = 1 to n.

Step 5: Analyze the results using histograms, summary statistics, confidence intervals, etc.

Variability

These are changes that occur in values of some components of the system. Variability can be *predictable* for example in changing the number of operators in a call centre during the day to meet changing call volumes or planned stoppages in a production facility. It may also be *unpredictable*, such as the arrival rate of patients at a hospital emergency department or the breakdown of equipment in a flexible manufacturing facility. Usually b forms of variability are present in most operations systems.

Example where there is component interconnectivity and possible variability: Customers arrive where they have to go though service points and take some predetermined time at each.

Combinatorial complexity

This is the behaviour of the system as related to the number of components in the system or the number of combinations of system components that are possible.

Examples of Combinatorial Complexity:

The travelling salesman problem is one in which a salesperson has to make a series of visits to potential customers during a day. The objective is to find the shortest route around those customers. For 8 cities there are 2520 possible combinations of routes and for 16 cities there are 6.5 × 1011 combinations of routes. The calculations are based on $(n - 1!)/2$, where n is the number of cities. So such a problem is subject to combinatorial complexity. Combinatorial complexity is present in some operations systems.

The job shop problem is another example. The parts are processed through a series of machines. In flow shop case, once the processing is complete on one machine, a part is passed to any one of the other machines, depending on the type of part and the next process required. The more machines there are in the job shop, the more the more the potential interconnections. As the number of machines increases so the interconnections increase at an even faster rate. Where are two interconnections between any two machines and the parts can move in either direction the total number of interconnections can be calculated as $n(n - 1)$, where n is the number of machines in the job shop. For 2 machines there are 2 interconnections but for 5 machines there are 20 interconnections.

Dynamic complexity

The is the behaviour of the system that arises from the interaction of components in a system over a period of time [Sterman, 2000]. Dynamic complexity can occur in small, as well as large systems.

Example of dynamic complexity: The ‘‘beer distribution game’’ is an example of dynamic complexity. This represents a simple supply chain consisting of a retailer, wholesaler and factory. The retailer orders cases of beer from the wholesaler, who in turn orders beer from the factory. There is a delay between placing an order and receiving the cases of beer. The game demonstrates that a small perturbation in the number of beer cases sold by the retailer can cause large shifts in the quantity of cases stored and produced by the wholesaler and factory respectively. The effects of dynamic complexity include [Senge ,1990] dramatic difference in effects of actions over short and long runs; difference in consequences of an action in different parts of a system; causing non-obvious consequences (counter intuitive behaviour). In feedback systems for example, the goods move in one direction for example in supply chains from the source to destination while information moves in the opposite direction.

Modeling and simulation as an enterprise?

Vendors, Application areas and markets

List of Vendors?

Agena: 32-33 Hatton Garden, London, EC1N 8DL, UK, www.agenarisk.com.
Alion Science and Technology: MA&D Operation; Boulder, CO 80301, www.maad.com.
AnalyCorp: 3507 Ross Rd., Palo Alto, CA 94303, www.AnalyCorp.com.
Applied Materials Inc: 5245 Yeager Rd, Salt Lake City, UT 84040, www.brookssoftware.com.
Averill M. Law & Associates: 6601 East Grant Road, Tucson, AZ 85715, www.averill-law.com.
Beliber AB: Bäckegatan 26 B, Gothenburg, Sweden, www.webgpss.com.
CACI Product's Company: 1455 Frazee Road, San Diego, CA 92108, caci.asl.com.
CMS Research Inc: 1610 S Main Street, Oshkosh, WI 54902, www.cmsres.com.
CreateASoft, Inc.: 1212 S. Naper Blvd. Ste 119, Naperville, IL 60540, www.simcadpro.com.
Custom Simulations: 1178 Laurel Street, Berkeley, CA 94708, customsimulations.com.
DecisionPath, Inc.: Winchester, MA 01890, www.decpath.com.
Flexsim Software Products, Inc.: Orem, UT 84097, www.flexsim.com.
Geer Mountain Software Corp.: Rolla, MO 65401, www.geerms.com.
Global Strategy Dynamics Ltd : Bucks, HP27 0XB, UK, www.strategydynamics.com/orms.
GoldSim Technology Group: Issaquah, WA 98027, www.goldsim.com.
Imagine That Inc: San Jose, CA 95119, www.extendsim.com.
Incontrol Enterprise Dynamics: China Township, MI 48054, www.EnterpriseDynamics.com.
Incontrol Enterprise Dynamics GmbH: Wiesbaden, Germany, www.showflow.com.
Lanner Group: Houston, TX 77042, www.lanner.com.
Lumina Decision Systems, Inc.: Los Gatos, CA 95033, www.lumina.com.
Mesquite Software: Austin, TX 78759, www.mesquite.com.
MJC2 Limited: Berkshire RG45 6LS, UK, www.mjc2.com.
Numerical Algorithms Group: Downers Grove, IL 60515, www.nag.com
Oracle's Crystal Ball Global Business Unit: Denver, CO 80202, www.crystalball.com
Palisade Corporation: Ithaca, NY 14850, www.palisade.com
ProcessModel, Inc.: Provo, UT 84601, www.processmodel.com.
ProModel Corporation: Allentown, PA 18195, www.promodel.com

QuantMethods: Pilot Point, TX 76258, www.quantmethods.com.
Renque Corporation: 2601 DE, The Netherlands, www.renque.com.
Rockwell Automation: Warrendale, PA 15086, www.ArenaSimulation.com .
Siemens (UGS, Tecnomatix, AESOP): Stuttgart 70499, Germany, www.emplant.com.
SIMUL8 Corporation: Boston, MA 02110, SIMUL8.com.
Stanislaw Raczynski: DF 14000, MEXICO, www.raczynski.com/pn/bluesss.htm.
Techno Software International: Kerala 682301, India, business.vsnl.com/ggrtech.
UGS Tecnomatix PLM Software: Stuttgart 70499, Germany, www.emplant.com.
Vanguard Software Corporation: Cary, NC 27518, www.vanguardsw.com.
Visual8 Corporation: Ontario L5G3H7, Canada, www.visual8.com & www.lean-modeler.com
Webb Systems Limited: Cheshire WA2 8TX, UK, www.showflow.co.uk/default2.htm.
Wolverine Software Corporation: Alexandria, VA 22305-2640, www.wolverinesoftware.com.
XJ Technologies: St.Petersburg 195220, Russia, www.anylogic.com

Vendor, application areas and markets

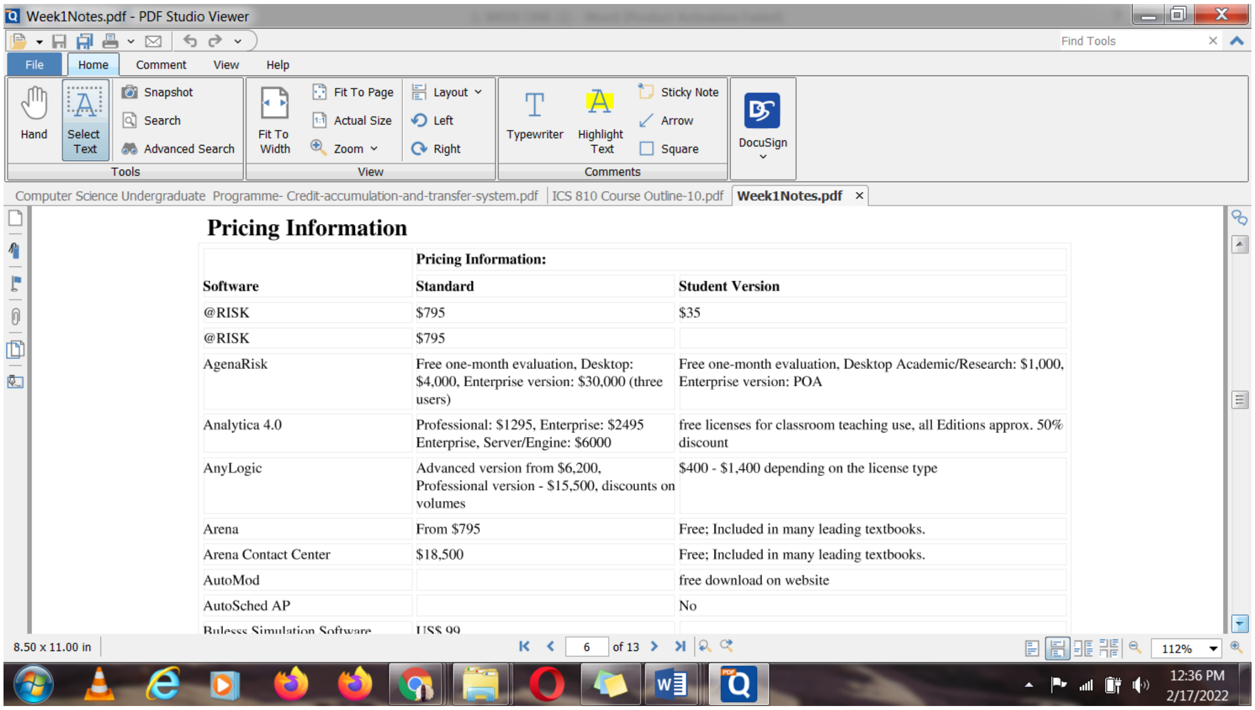
Software	Vendor	Typical Applications of the software	Primary Markets for which the software is applied
@RISK	Palisade Corporation	@RISK is a risk analysis tool using Monte Carlo simulation to show all possible outcomes, and their likelihood of occurrence.	Manufacturing, energy, finance, insurance, six sigma, medical, agriculture, transportation, government, academic, environment
AgenaRisk	Agena	Probability analysis, statistical simulation, artificial intelligence, bayesian networks, business modeling, risk assessment,	Industry, government, education, telecommunications, financial services, healthcare, pharmaceuticals, energy, environment, re
Analytica 4.0	Lumina Decision Systems, Inc.	Investment, risk, decision, portfolio network flow analysis; systems dynamics; resource, R&D planning; organization simulatio	Business, financial, public policy, energy, environmental, healthcare, defense, manufacturing, education, telecommunication
AnyLogic	XJ Technologies	Forecasting and strategic planning, process analysis and optimization, optimal operational management, process visuallization	Logistics, supply chains, manufacturing, healthcare, consumer markets, project management, busines processes, military
Arena	Rockwell Automation	Facility design/configuration, scheduling, passenger and baggage-handling processes, patient management, dispatching strategy	Airports, healthcare, logistics, supply chain, mfg., military, business process, call centers, steel, paper, mining, ports
Arena Contact Center	Rockwell Automation	Staffing, work strategies, campaign planning, customer metrics, back office, skill-based routing, ...	Call centers and contact centers of all types, single/multi-site, local/global, unlimited size/complexity
AutoMod	Applied Materials	Discrete event simulation to improve the design, configuration and	Distribution centers, warehouses, automotive, airports,
AutoMod	Applied Materials Inc.	Discrete event simulation to improve the design, configuration and optimization of material handeling processes	Distribution centers, warehouses, automotive, airports, equipment, shipping, semiconductor, and manufacturing
AutoSched AP	Applied Materials Inc	Capacity analysis and planning and short interval scheduling	Semiconductor industry
Bulesss Simulation Software	Stanislaw Raczynski	General purpose simulation system. Generates C++ source code.	Academic, engineering, industry, manufacturing
Certified Distributions for use with Monte Carlo simulation	AnalyCorp	Probability management, see http://www.lionhrtpub.com/orms/ orms-2-06/frprobability.html	Project portfolio, supply chain, finance
Crew Station Design Tool (CSDT)	Alion Science and Technology	The CSDT allows users to visualize and optimize the location of controls and displays within a crew station.	Aviation (e.g., aircraft cockpits), military, nuclear power plants, and car manufacturers
Crystal Ball Professional	Oracle's Crystal Ball Global Business Unit	Business planning and analysis, cost/benefit analysis, risk management, petroleum exploration, environmental assessment . . .	Financial services, environmental, oil and gas, pharmaceuticals, telecom, manufacturing, energy, utilities, insurance . . .
Crystal Ball Standard	Oracle's Crystal Ball Global Business Unit	Investment and financial; cost and benefit analysis; risk and project management; petroleum exploration; Six Sigma . . .	Financial services, environmental, oil and gas, pharmaceuticals, telecom, manufacturing, energy, utilities, insurance . . .
CSIM 19	Mesquite Software	Modeling systems	Computer systems, communications, education, research
CSIM for Java	Mesquite Software	Modeling complex systems	Education, research

	Dynamics	process improvement, capacity planning	electronics, food and beverage, consumer goods
ExpertFit	Averill M. Law & Associates	discrete-event simulation, Monte Carlo simulation, data analysis in general	defense, manufacturing, transportation, education
ExtendSim AT	Imagine That Inc.	It is particularly well-suited to manufacturers operating in a mixed-mode environment: batch process and discrete event.	Any industry that operates in a high-speed or high-volume arena: distribution logistics, call centers, packaging lines, etc.
ExtendSim OR	Imagine That Inc.	Message-based discrete event architecture to model processes involving physical or logical objects moving through systems.	Manufacturing and business modeling; communication systems, healthcare, Six Sigma, transportation, service, education, etc.
ExtendSim Suite	Imagine That Inc.	Professional 3D modeling of continuous, discrete event and discrete rate processes.	When impressive presentations count. 3D modeling of manufacturing, logistics, business, government, eductation, engineering..
Flexsim CT (Container Terminals)	Flexsim Software Products, Inc.	Simulation of container ports including: yard, land, sea, and rail, cranes, gangs, yard blocks, carriers. Links with TOS	Terminal operating companies, port consultants, TOS providers, port automation integrators, homeland security
Flexsim Simulation Software	Flexsim Software Products, Inc.	Manufacturing, material handling, warehousing, supply chain, process improvement, lean, healthcare, continuous, food	Manufacturing, healthcare, distribution, warehousing, supply chain, transportation, food processing, logistics
Flexsim Warehouse Analyzer	Flexsim Software Products, Inc.	Use to analyze slotting and picking of warehouse operations	Warehousing, slotting, layout, building configuration and optimization.
ForeTell-DSS	DecisionPath, Inc.	Critical decision support, org. change mgmt, competitive marketing	Government, life sciences, financial services
GoldSim	GoldSim Technology Group	water resources, mining, hazardous waste management, probabilistic risk analysis, reliability and throughput analysis	Mining, water resources, aerospace and defense, engineering and management consulting, insurance, waste management
GPSS/H	Wolverine Software Corporation	Queueing models	General purpose
Integrated Performance Modelling Environment (IPME)	Alion MA&D Operation	Human factors, human performance modeling, examining stressors in environments	Military, nuclear, transportation, academia
L-SIM	Lanner Group	Java based Simulation Component for embedding into 3rd party Process or Application suites	Manufacturing, aerospace & defense, federal, homeland security, pharmaceuticals, energy, aviation, health, IT
Lean-Modeler	Visual8 Corporation	Value stream mapping, lean implementation, process improvement	Automotive, energy, health care, logistics, manufacturing, metals, business process re-engineering
MAST	CMS Research Inc	MAST uses part routing and production information to determine kanban loops, product flows, and optimal operation plan	Lean manufacturing implementation: analysis of process maps
MedModel Optimization Suite	ProModel Corporation	Design, plan, evaluate and improve processes of hospitals, clinics, and other healthcare systems to optmize performance	Hospitals, Clinics, Healthcare Systems, Medical Device Manufacturing and Sales
Micro Saint Sharp	Alion Science and Technology	Micro Saint Sharp is a powerful general-purpose discrete event simulation tool that allows users to build models of processes	Typical markets include human performance, manufacturing, healthcare, supply chain, and command and control modeling.
mystrategy	Global Strategy	Business and strategy planning	Not industry-specific. Used by strategy professionals and

mystrategy	Global Strategy Dynamics Ltd	Business and strategy planning	Not industry-specific. Used by strategy professionals and wider management as alternative to dynamic modeling spreadsheets
NAG C Library	Numerical Algorithms Group	product pricing optimization, portfolio optimization, statistical analysis, fluid dynamics	finance,energy,engineering,education,earth sciences,life sciences
NeuralTools	Palisade Corporation	New drug effectiveness, power grid fault detection, tumor & tissue , quality control & Six Sigma, structural fault detection.	Manufacturing, energy, insurance, medical, Six Sigma, agriculture, finance, transportation, government, academic, environment
Plant Simulation (=eM-Plant ; =SiMPLE++)	Siemens (UGS, Tecnomatix, AESOP)	Plant Simulation enables the simulation and optimization of production systems.	Automotive; Suppliers; Shipyards; Electronic and White goods; CPG; Line Builder; Design houses
Portfolio Simulator	ProModel Corporation	Simultaneous simulation analysis and optimization of multiple project plans across the entire portofolio of projects.	Project and Portfolio Planning, Strategic Resource Capacity Planning; New Product Development, R&D, Scheduling
Process Simulator	ProModel Corporation	Lean, Six Sigma, value stream mapping, process mapping, flow chart simulation, continuous process improvement	All
ProcessModel Professional	ProcessModel, Inc.	Business process improvement - all areas	All
Profimax, Techno Therm Plus, Technical	Techno Software International	Profit, productivity, performance maximization, energy, environment, maintenance, production management & auditing	Process, power plants, design organizations

Software	**RAM**	**Operating Systems**
@RISK	32	Microsoft Windows 2000 or higher
AgenaRisk	256MB min	Windows XP/2000, Unix, Linux
Analytica 4.0	128	Windows 98, 2000, NT, XP, Vista
AnyLogic	512MB, 1GB recommended	Windows. Mac OS, Linux
Arena	128M	Windows 2000/Server 2003/XP/Vista (in V12)
Arena Contact Center	128M	Windows 2000/Server 2003/XP/Vista (in V12)
AutoMod	1 GB	Window XP Professional
AutoSched AP	1 gig min	Windows XP
Bulesss Simulation Software	248Mb	Windows 98 or later, NT, XP, requires Borland's C++Builder
Certified Distributions for use with Monte Carlo simulation		
Crew Station Design Tool (CSDT)	256 MB RAM	Microsoft Windows XP, 2000, or NT
Crystal Ball Professional	512 MB	Microsoft Windows 2000, XP and Vista
Crystal Ball Standard	512 MB	Microsoft Windows 2000, XP and Vista
CSIM 19	1 - 1000 MB	Windows, Linux, Solaris

CSIM for Java	10 - 1000MB	Any system with Java
eM-Plant	128 MByte	Microsoft Windows 2000, Microsoft Windows XP
Emergency Department Simulator	128MB min, 512MB recommended	Windows 2000, XP
Enterprise Dynamics	64Mb	Windows 98/2000/XP/Vista
ExpertFit	minimal	Windows
ExtendSim AT	512 MB	Windows Vista, XP, 2000, 2003 Server, or better
ExtendSim OR	512 MB	Windows Vista, XP, 2000, 2003 Server, or better
ExtendSim Suite	512 MB	Windows Vista, XP, 2000, 2003 Server, or better
Flexsim CT (Container Terminals)	512	Windows (XP, 2000, Vista)
Flexsim Simulation Software	512	Windows (XP, 2000, Vista)
Flexsim Warehouse Analyzer	512	Windows (XP, 2000, Vista)
ForeTell-DSS	512 MB	Windows, Mac OS, Linux
GoldSim	256	Windows 2000 and above
GPSS/H	256 MB	Windows 2000/XP/Vista
Integrated Performance Modelling Environment (IPME)	512MB	Windows XP, Windows 2000, RedHat Enterprise Linux, Mandrake Linux 10.X
L-SIM	256MB	Windows 2000, NT, XP and VISTA
Lean-Modeler	minimum 64MB	Windows 95, 98, ME, NT 4, 2000, XP, Vista
MAST		Windows 2000 or higher
MedModel Optimization Suite	512MB min; Recommend 1 GB	Windows 2000, XP
Micro Saint Sharp	128MB	Microsoft Windows Vista, Server 2003, XP, 2000, 98, ME (Operating systems must support the Microsoft .NET Framework 2.0)
mystrategy	32MB min., 64MB+ recom.	Windows 98SE or later
NAG C Library	problem-dependent	Windows(NT/XP/Vista), Linux, Solaris, AIX, HP-UX, Mac OS X
NeuralTools	32 MB	Microsoft Windows 2000 or higher
Plant Simulation (=eM-Plant ; =SiMPLE++)	128 MB RAM	Microsoft Windows 2000 with SP 4 or Windows XP
Portfolio Simulator	512MB min; Recommend 1 GB	Windows 2000, XP
Process Simulator	512MB min.; recommend 1 GB	Windows 2000, XP, Vista; Also needs MS Visio 2002, 2003 or 2007



Pricing Information

	Pricing Information:	
Software	**Standard**	**Student Version**
@RISK	$795	$35
@RISK	$795	
AgenaRisk	Free one-month evaluation, Desktop: $4,000, Enterprise version: $30,000 (three users)	Free one-month evaluation, Desktop Academic/Research: $1,000, Enterprise version: POA
Analytica 4.0	Professional: $1295, Enterprise: $2495 Enterprise, Server/Engine: $6000	free licenses for classroom teaching use, all Editions approx. 50% discount
AnyLogic	Advanced version from $6,200, Professional version - $15,500, discounts on volumes	$400 - $1,400 depending on the license type
Arena	From $795	Free; Included in many leading textbooks.
Arena Contact Center	$18,500	Free; Included in many leading textbooks.
AutoMod		free download on website
AutoSched AP		No
Bulesss Simulation Software	US$ 99	

Bulesss Simulation Software	US$ 99	
Certified Distributions for use with Monte Carlo simulation	Contact Info@AnalyCorp.com	
Crew Station Design Tool (CSDT)	$15,000	N/A
Crystal Ball Professional	$1,895	$95
Crystal Ball Standard	$995	$85
CSIM 19	Professional - $1195; Education - $360	Student - $65
CSIM for Java	Professional - $1195; Educational - $360	$65
eM-Plant		
Emergency Department Simulator	$ 39,000	N/A
Enterprise Dynamics	Ranging from 5,000 - 27,000	Free
ExpertFit	$325 - $795	
ExtendSim AT	$2495; academic discounts are available.	$125; discounts available for students.
ExtendSim OR	$995; academic discounts are available.	$125; discounts available for students.
ExtendSim Suite	$4995; academic discounts are available.	$125; discounts available for students.
Flexsim CT (Container Terminals)	$45,000	n/a
Flexsim Simulation Software	$15,000-$20,000	Free

Flexsim Warehouse Analyzer	$20,000	n/a
ForeTell-DSS	Contact DecisionPath	Contact DecisionPath
GoldSim	$3950	free
GPSS/H	Several versions available	Free
Integrated Performance Modelling Environment (IPME)	$15,000	$75
L-SIM		
Lean-Modeler	$695 US (network licenses also available)	N/A
MAST	$7500.00	$750.00
MedModel Optimization Suite	$18,500	$30
Micro Saint Sharp	$4995	$60
mystrategy	£165.00 plus VAT	£15.00 plus VAT (5 month license only)
NAG C Library	please contact us	please contact us
NeuralTools	$495.00	
Plant Simulation (=eM-Plant ; =SiMPLE++)	http://www.ugsplmsolutions.de/produkte/tecnomatix/plant_design/em_plant.shtml	yes

Portfolio Simulator	$39,000	N/A
Process Simulator	$ 3500	PCS Lite - Free Download
ProcessModel Professional	Complete solutions start at $1,098.00	$69.00 limited use
Profimax, Techno Therm Plus, Technical Audit, Techno Maint, Techno Plan, Techno Corr, Techno Blend,Process Models for HPI	Varies between 12500 to 15000 US$/copy.	30% discount shall be offered only for genuine students.
Project Simulator	$3500	Free Trial Version
ProModel Optimization Suite	$ 18,500	$ 30
Proof Animation	Several versions available	Free
Quantitative Methods Software (QMS)	USD $19.95 for 6 month subscription	USD $19.95 for 6 month subscription
Renque	995	0
SAIL	$25,000 US	$ 2,500
ServiceModel Optimization Suite	$18,500	$ 30
ShowFlow 2	GBP 895	GBP 25
ShowFlow Simulation Software	Ä 1295,00 plus shipping & VAT	free demoversion available
Sigma	$5000 annual commercial license - deeply	For university courses only - no individual student licenses.

Application Areas and Markets??

Session topics: What, why, when, Time, Variability, Distributions and the related issues with modeling and simulation.

What is modeling and simulation? ----Recap

Simulation is the *experimentation* with a *simplified imitation* (on a computer) of an *operations system* as it progresses through time, for the purpose of *better understanding and/or improving* that system [Robinson Stewart, 2004].

Why should simulation be necessary?

- To gain the insight necessary for making some decisions: eg for example in a simulation of a port it may be necessary to model the tidal and weather conditions for purposes of advising ships not to enter the port.
- To make use of models in understanding, changing, managing and controlling reality. In particular, this involves understanding and/or identifying ways of improving a system.
- Inform decision-making on the real system regarding the future items.
- To enable the prediction of the performance of an operations system under a specific set of inputs. For example, it might predict the average waiting time for telephone customers at a call centre when a specific number of operators are employed.
- To allow a ‘‘what-if’’ analysis as the user enters a scenario and the model predicts the outcome. The alternative scenarios may be explored until the experimenter has obtained sufficient understanding or identified how to improve the real system. It thus acts as a decision support system [Robinson, 2004].
- To handle a problem that is too complicated to solve analytically.
- To handle tractable problem *(Easily solved or worked)* whose level of detail provided by the analytical answers is insufficient for the required needs.
- To put a new concept into practice on an experimental basis and see if it produces the desired results;
- *Provide a higher level of detail* than other techniques.
- Provide (approximate) *answers at a lesser cost (or effort)* to some problems which are fully tractable mathematically but whose solution may be cumbersome and time consuming.
- *Permit modification or design*of systems by *trial and error*.
- Allows for easy *exploration of the system's sensitivity* to changes in the input parameters, and provides *a highly controllable environment* for experiments.
- *To test the applicability and validity of mathematical models and expressions*.
- To gain insight and predictions in a system that is complex and has variability and several component interconnections.

- To predict the performance of systems that have interconnected components and have both combinatorial and dynamic complexity.

Advantages of simulation

Simulation is better than working with the *real system:-*

- *Simulation is less costly,* while experimentation with the real system can be very expensive. Consider for example interrupting day-to-day operations in order to try out new ideas. The shut downs may lead to loss of customers or customer dissatisfaction.
- *Simulation takes less time,* while an experiment with a real system may take many weeks or months before a true reflection of the performance of the system can be obtained. With simulation the, results on system performance can be obtained in a matter of minutes, maybe hours. The faster experimentation also enables many ideas to be explored in a short time frame.
- *Simulation enables easier control of the experimental conditions,* which is useful in comparing alternatives. This can be very difficult when experimenting with the real system. For example consider the difficulty of controlling the arrival of patients at a hospital.
- *Simulation can be used even where the real system does not exist,* such as the case of a new yet to be built school, football stadium or hospital.
- Simulation is better than other modeling approaches (simple paper calculations, spreadsheet models, heuristic methods, linear programming, dynamic programming and genetic algorithms):
- *Simulations can cope with modeling variability,* other methods that are mentioned are not able to do so. This is often due to increases in their complexity. Some systems cannot be modeled analytically.
- -*Simulations have fewer restrictive assumptions* compared to other methods for example queuing theory, often assumes particular distributions for arrival and service times while for many processes these distributions are not appropriate. In simulation, any distribution can be selected.
- -*Simulations provides more transparency* to the manager than other methods because it is more intuitive more so if the display is animated any non-expert greater understanding of, and confidence in, the model.
- Simulation gives managers particular benefits:
    - *Simulation fosters creativity*by allowing trials without fear of failure.
    - *Simulation leads to the creation of knowledge and understanding* as it forces the management to take time examining the problem given ‘problem specified is half solved’.

- *Simulation with visualization and communication* enable easier demonstration of ideas to management.
- *Simulation enables consensus building* as it provides a powerful tool for sharing concerns and testing ideas. Sometimes opinions are at variance for example in a factory, managers and workers may not agree over working hours and shifts

Some issues with simulation

- *Simulation software can be expensive*, especially where consultants have to be employed.
- *Simulation can be time consuming* since sometimes it needs much time to get useful results.
- *Simulation can be data hungry* and this can present a problem where significant amount of data is needed and it is not immediately available.
- *Simulation requires expertise* as it is beyond the development of a computer program or the use of a software package. It requires skills in, among other things, conceptual modeling, validation and statistics, as well as skills in working with people and project management.
- *Overconfidence in simulation can be a problem* specially when anything produced on a computer is seen to be right. Usually interpreting the results from a simulation, requires checking the validity of the underlying model and the assumptions and simplifications that have been made [Robinson, 2004].
- *Developing cause-and-effect relationships* through simulation can be difficult, especially when the system under consideration requires the specification of many input parameters and involves complex interactions.
- *The statistical analysis of simulation results is difficult* especially determining the effect of the starting conditions of the simulation on the final results.

When to use simulation

Where features involve the entities that are being processed through a series of stages, such as queuing systems. There are very many areas where simulation can be used and they include:

- Manufacturing systems;
- Public systems: health care, military, natural resources, agriculture;
- Transportation systems; Construction systems
- Restaurant and entertainment systems

- Business process reengineering/management;
- Food processing;
- Computer system performance
- Service and retail systems
  [Banks et al, 1996]

Some basic principles in Simulation

Tools: specialist software do not require programing from scratch.
Key elements in simulation software:-

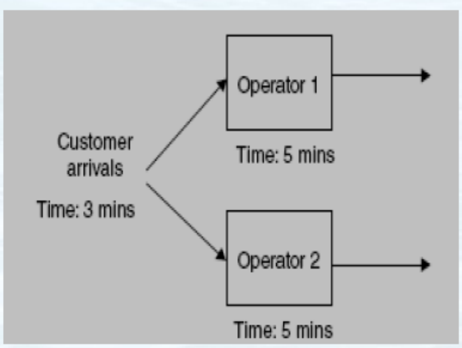
- modeling the progress of time - present in all dynamic simulations
- modeling variability - present in the majority of simulation software

Modeling the progress of time using time-slicing

The progress of time is modeled using a constant time-step (Δ_t).
Example [Robinson, 2004].

$$t_{n+1} = t_n + \Delta_t$$

Modeling the progress of time using time-slicing- call center example



Time	Call arrival	Operator 1	Operator 2
0	3		
1	2		
2	1		
3	3	5	
4	2	4	
5	1	3	
6	3	2	5
7	2	1	4
8	1		3
9	3	5	2
10	2	4	1
11	1	3	
12	3	2	5
13	2	1	4
14	1		3
15	3	5	2
16	2	4	1
17	1	3	
18	3	2	5
19	2	1	4
20	1		3
21	3	5	2
22	2	4	1
23	1	3	
24	3	2	5
Completed calls		3	3

Call center, source: [Robinson, 2004 pg.15]

Limitations of the Time-slicing approach

Inefficiency. For example consider the many time-steps where there is no change in the system-state making the many computations are unnecessary. The only points of interest are when a call arrives, when an operator takes a call and when an operator completes a call and there are 22 points in total. However 72 (24×3) calculations are performed.

Non obvious value of Δ_t. The second problem is determining the value of Δ_t. In the example above time can be counted in whole numbers. However, there can be a wide variation in activity times within a model from possibly seconds (or less) through to hours, days, weeks or more.

Modeling the Progress of Time Using the Discrete-Event Simulation Approach

- Only the points in time at which the state of the system changes are represented.
- The system is modeled as a series of events, which are the, instants in time when a state-change occurs.
- Examples of events: a customer arrives, a customer starts receiving service and a machine is repaired. Each of these occurs at an instant in time.

Modeling the Progress of Time Using the Discrete-Event Simulation Approach

Time	Event
3	Customer arrives
	Operator 1 starts service
6	Customer arrives
	Operator 2 starts service
8	Operator 1 completes service
9	Customer arrives
	Operator 1 starts service
11	Operator 2 completes service
12	Customer arrives
	Operator 2 starts service
14	Operator 1 completes service
15	Customer arrives
	Operator 1 starts service
17	Operator 2 completes service
18	Customer arrives
	Operator 2 starts service
20	Operator 1 completes service
21	Customer arrives
	Operator 1 starts service
23	Operator 2 completes service
24	Customer arrives
	Operator 2 starts service

Discrete Event [Robinson, pg. 16]

Some basic principles in Simulation

The three-phase simulation approach for discrete events

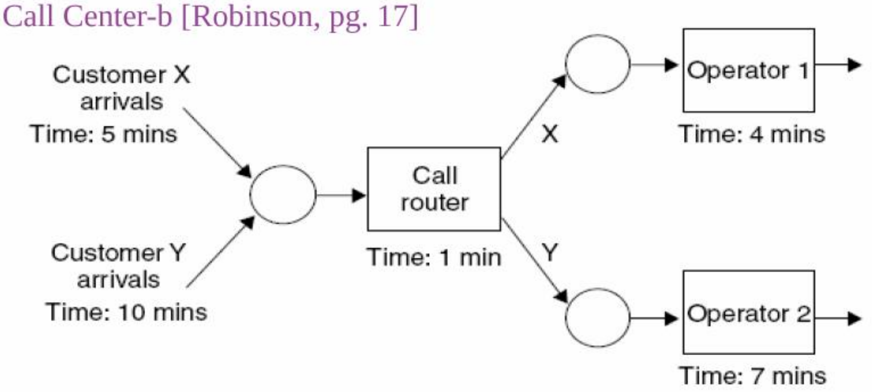
The events are classified into two types: the bound or booked events (B) and the conditional (C) events.

B (bound or booked) events: are state changes that are scheduled to occur at a point in time.
Examples: call arrivals in the call centre model that occur every 3 minutes. Usually the B-events are related to the arrivals or the completion of activities.

C (conditional) events: are state changes that are dependent on the conditions in the model.
Examples: an operator that can only start serving a customer *if* there is a customer waiting to be served and the operator is not busy. Usually the C-events are related to the start of some activities.

The three-phase simulation approach for discrete events

Call Center-b [Robinson, pg. 17]



Customers: X, Y -make calls. X calls arrive every 5 minutes; Y calls arrive every 10 minutes. A queue (denoted by a circle) is used to hold the calls before the call router directs the call to the right operator. The routing activity takes 1 minute. Operator 1 the first takes all customer X calls, operator 2 takes customer Y calls. Operator 1 takes exactly 4 minutes to deal with a call and operator 2 exactly 7 minutes.

The three-phase simulation approach for discrete events

Event	Type	Change in state	Future events to schedule
B1	Arrival	Customer X arrives and enters router queue	B1
B2	Arrival	Customer Y arrives and enters router queue	B2
B3	Finish activity	Router completes work and outputs X to operator 1 queue, Y to operator 2 queue	
B4	Finish activity	Operator 1 completes work and outputs to world (increment result work complete X by 1)	
B5	Finish activity	Operator 2 completes work and outputs to world (increment result work complete Y by 1)	

Event	Type	Condition	Change in state	Future events to schedule
C1	Start activity	Call in router queue and router is idle	Router takes call from router queue and starts work	B3
C2	Start activity	Call is in operator 1 queue and operator 1 is idle	Operator 1 takes call from operator 1 queue and starts work	B4
C3	Start activity	Call is in operator 2 queue and operator 1 is idle	Operator 2 takes call from operator 2 queue and starts work	B5

B- and C – Events: Call center –b

The three-phase simulation approach for discrete events

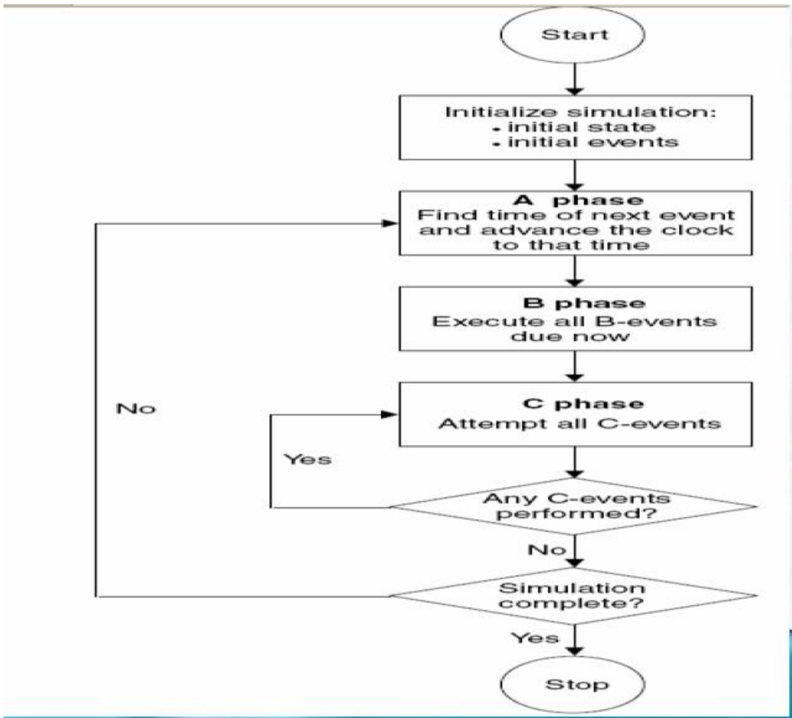
The Process

Initialization process: the initial B-events are scheduled eg. The arrival of the first customers. The event list that keeps a record of all future events that have been scheduled is set up. The simulation then moves into three phases that are continuously repeated:

The A-phase, also called the simulation executive, is where the time of the next event is determined by inspecting the event list. The simulation clock is then advanced to the time of the next event.

The B-phase, is whereall B-events that are due at the appropriate clock time are executed.

The C-phase, is where all C-events are attempted and those for which the conditions are met are executed. The simulation continues to attempt C-events until no further events can be executed. The simulation then repeats from the *A-phase* unless it is deemed that the simulation is complete.



The Three-Phase Simulation Approach- Call Center-b [Robinson, pg. 19]

The three-phase simulation approach for discrete events

Model Status

Phase	Router queue	Router	Oper. 1 queue	Oper. 1	Oper. 2 queue	Oper. 2
	Empty	Idle	Empty	Idle	Empty	Idle

Event List

Event	Time
B1	5
B2	10

Results

	Work complete
X	0
Y	0

Call Centre Simulation: Clock = 0 (Initialize Simulation).

The three-phase simulation approach for discrete events

Model Status

Phase	Router queue	Router	Oper. 1 queue	Oper. 1	Oper. 2 queue	Oper. 2
B	X1	Idle	Empty	Idle	Empty	Idle
C	Empty	X1	Empty	Idle	Empty	Idle

Event List

Event	Time
B3	6
B2	10
B1	10

Results

	Work complete
X	0
Y	0

Call Centre Simulation: Clock = 5 (Event B1).

The three-phase simulation approach for discrete events

Model Status

Phase	Router queue	Router	Oper. 1 queue	Oper. 1	Oper. 2 queue	Oper. 2
B	Empty	Idle	X1	Idle	Empty	Idle
C	Empty	Idle	Empty	X1	Empty	Idle

Event List

Event	Time
B2	10
B1	10
B4	10

Results

	Work complete
X	0
Y	0

Call Centre Simulation: Clock = 6 (Event B3).

The three-phase simulation approach for discrete events

Table 2.12 Call Centre Simulation: Clock = 16 (Events B4, B3).

Model Status

Phase	Router queue	Router	Oper. 1 queue	Oper. 1	Oper. 2 queue	Oper. 2
B	Empty	Idle	X3	Idle	Empty	Y1
C	Empty	Idle	Empty	X3	Empty	Y1

Event List

Event	Time
B5	18
B2	20
B1	20
B4	20

Results

Work complete	
X	2
Y	0

Call Centre Simulation: Clock = 16 (Event B3, B4).

The three-phase simulation approach for discrete events

Model Status

Phase	Router queue	Router	Oper. 1 queue	Oper. 1	Oper. 2 queue	Oper. 2
B	Empty	Idle	Empty	X3	Empty	Idle
C	Empty	Idle	Empty	X3	Empty	Idle

Event List

Event	Time
B2	20
B1	20
B4	20

Results

Work complete	
X	2
Y	1

Call Centre Simulation: Clock = 18 (Event B5).

MODELING VARIABILITY

Variability - the changes that occur in the components of the system as time goes on. Variability can be predictable or unpredictable. We focus on modeling unpredictable variability as it presents the key challenge.

Modeling unpredictable variability

Call center example: variability may arise from calls arrivals, the time it takes the calls to be routed, and the time that the operators take to process the calls. Unpredictable variability is handled using the random numbers.

Random numbers

Are a sequence of numbers that appear in some random order. They can be integers (whole) numbers on a scale of say 0 to 99 or 0 to 999, or as real numbers (with decimal places) numbers on a scale of 0 to 1.

Important properties of random numbers

Uniformity - each number has the same probability of occurring

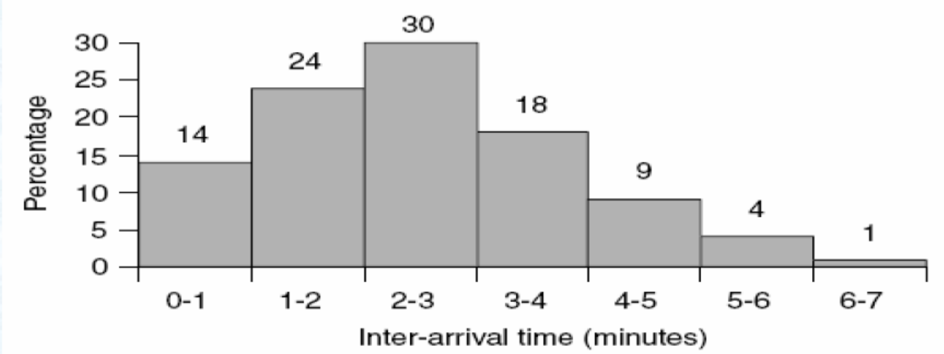
Independence - the occurrence of any number is not influenced by other numbers.

Most of the development software environments today including spreadsheets have facilities for generating random numbers. During earlier times there were some random number tables that could be used.

Variability in proportions can be modeled by direct size comparisons such as in a space of 0-999 how many are below 400? For types we can have 0-60 of type X and 61-
99 of type Y.

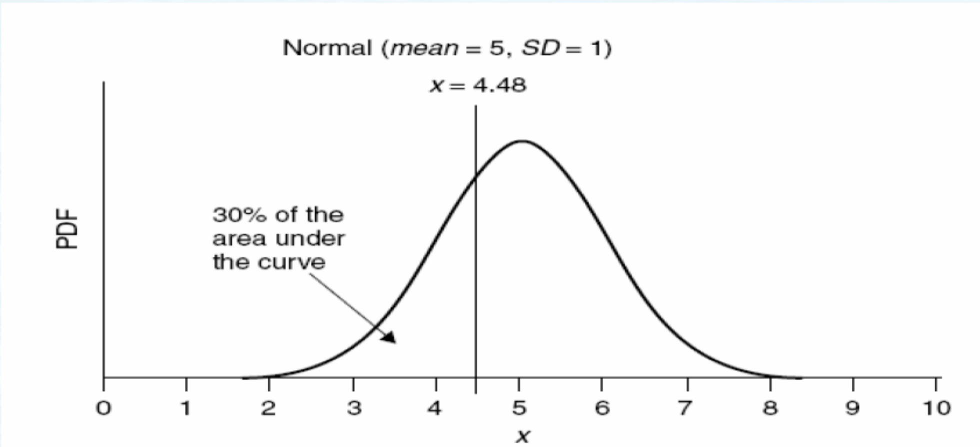
Modeling variability that are related to time

Examine the frequency of occurrence over a given period of time. Consider the time it takes between two calls to arrive and a situation where it varies from 0 -7. This can be as shown on the figure below.



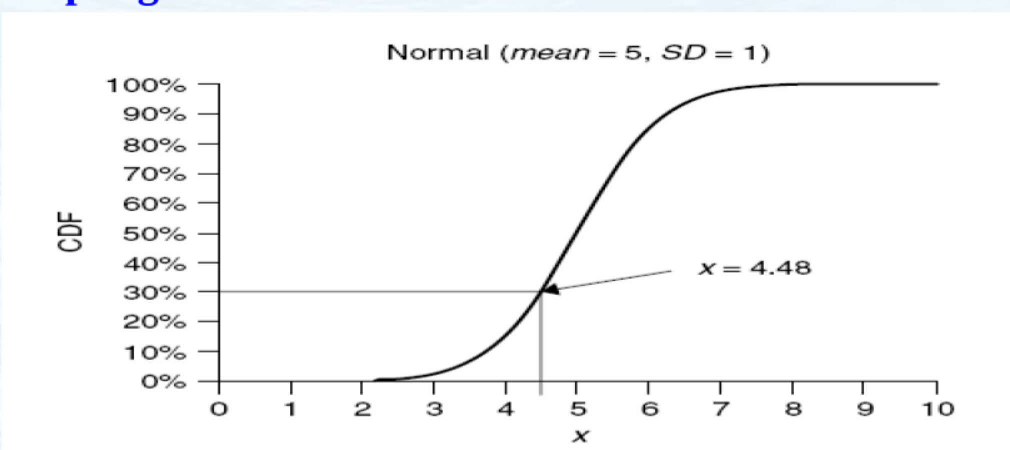
Frequency Distribution for Inter-Arrival Time of Calls [Robinson, p.28]

Sampling from standard statistical distributions



A normal distribution [Robinson, p.31]

Sampling from standard statistical distributions



Cumulative distribution functions from the Normal Distribution- to avoid areas as in the previous slide

Sampling from standard statistical distributions

Computer generated random numbers

Needed to meet large demand of thousands or even millions of random numbers.

The random numbers that are generated are known as *pseudo random numbers*.

An algorithm for generating such random numbers is as follows:

$$X_{i+1} = [aX_i + c\,](mod\ m), \text{ where:}$$

X_i **: stream of random numbers (integer) on the interval** $(0, m-1)$

a **: multiplier constant;** c **: additive constant**

m **: modulus;** ***mod m*** **means take the remainder having divided by** m

Sampling from standard statistical distributions

Computer generated random numbers

$$X_{i+1} = [aX_i + c\,](mod\ m), \text{ where:}$$

X_i : stream of random numbers (integer) on the interval $(0, m-1)$

a : multiplier constant; c : additive constant

m : modulus; *mod m* means take the remainder having divided by m

Example

When $X_0 = 8$, $a = 4$, $c = 0$ and $m = 25$. This gives random numbers on a range of 0 to 24, the maximum always being one less than the value of m. Note that the stream repeats itself after $i = 9$. Carefully select the constants.

Some common statistical distributions

Beta ($Shape_1$, $Shape_2$)

Potential applications: **time to complete a task; proportions (e.g. defects in a batch of items); useful as an approximation in the absence of data, task times in Pert networks.**

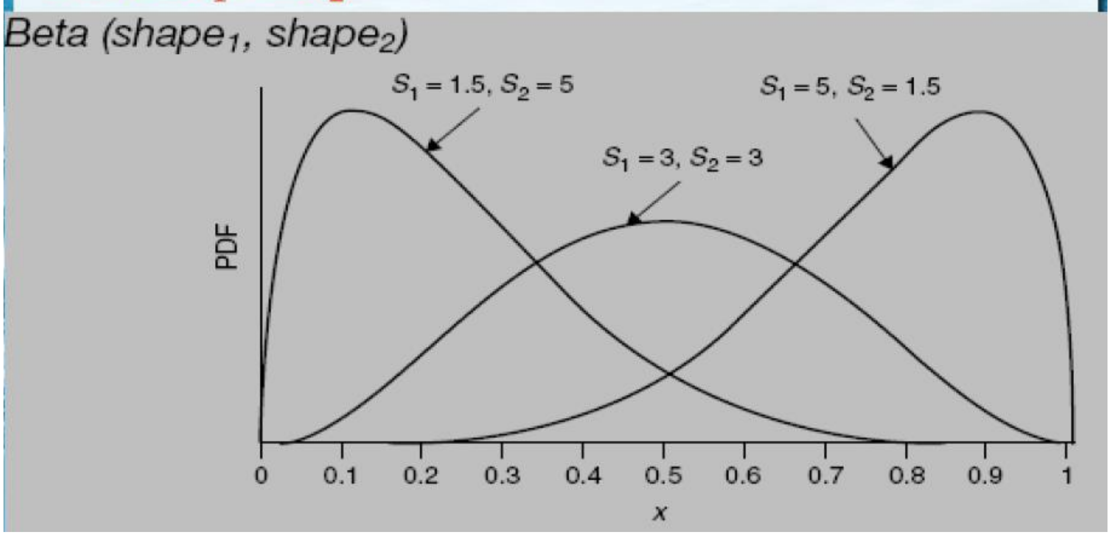
***Mean*:** $(shape_1) / (shape_1 + shape_2)$

***Standard deviation*:** $\sqrt{[(shape_1 \times shape_2) / (shape_1 + shape_2)^2 (shape_1 + shape_2 + 1)]}$

***Range of values*:** **$0 < x < 1$ (use a multiplier to extend the range)**

Some common statistical distributions

Beta ($Shape_1$, $Shape_2$):



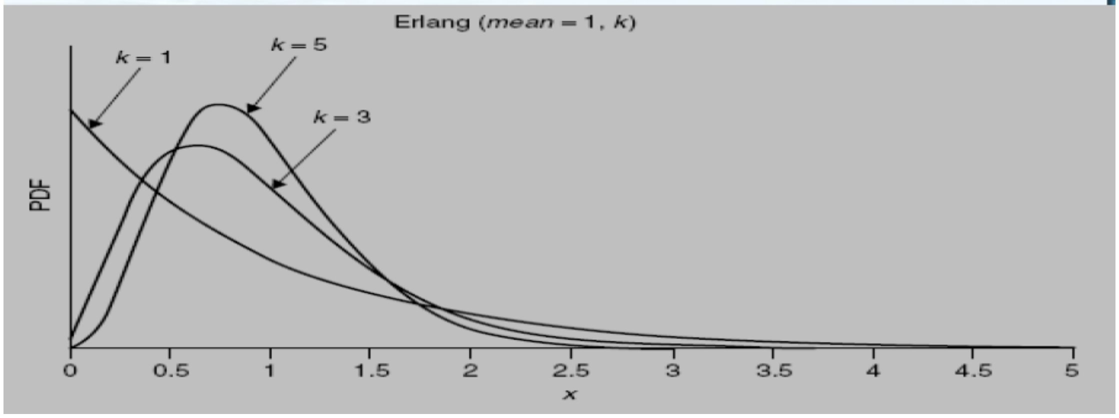
Erlang (mean k)- special form of Gamma distribution

***Potential applications*: time to complete a task; inter-arrival times (e.g. customer arrivals); time between failure, queuing theory**

***Mean*: mean=k**

***Standard deviation:* (mean)/ (√k)**

***Range of values:* 0< x < ∞**

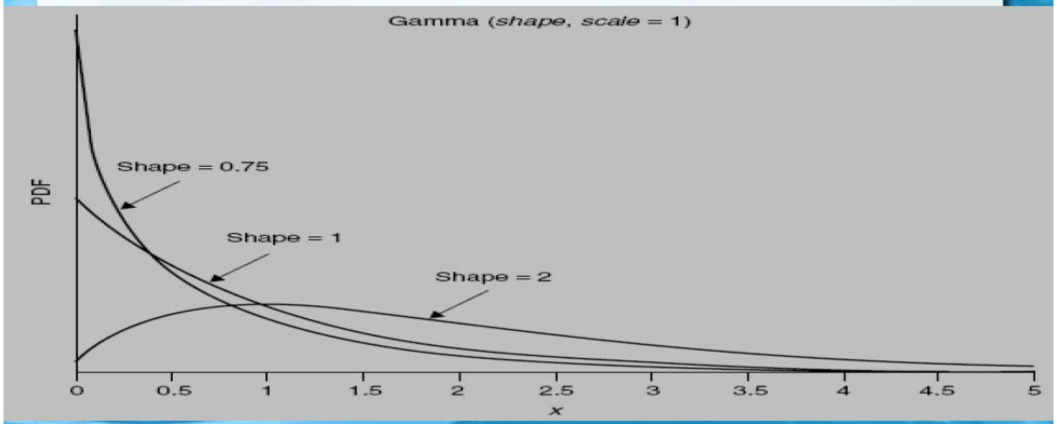


Gamma (shape, scale)

***Potential applications:* time to complete a task; inter-arrival times (e.g. customer arrivals, time between failure)**

***Mean*: shape × scale; *Standard deviation:* √(shape × scale);**

***Range of values*: 0< x < ∞**



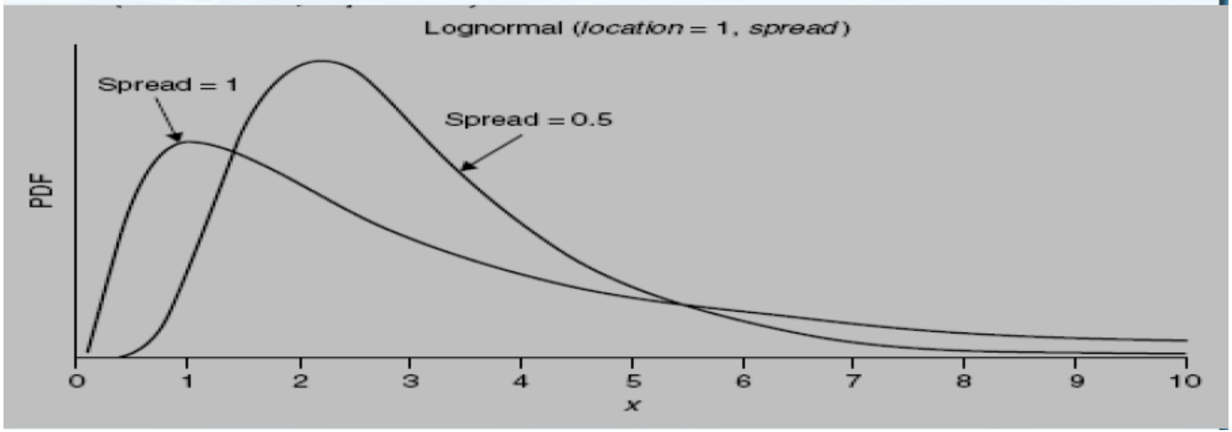
Lognormal (location, spread)

***Potential applications*: time to complete a task;**

***Mean*: $e^{location+spread/2}$**

***Standard deviation*: $\sqrt{(e^{2location+spread}(e^{spread} - 1))}$**

***Range of values*: $0 < x < \infty$**



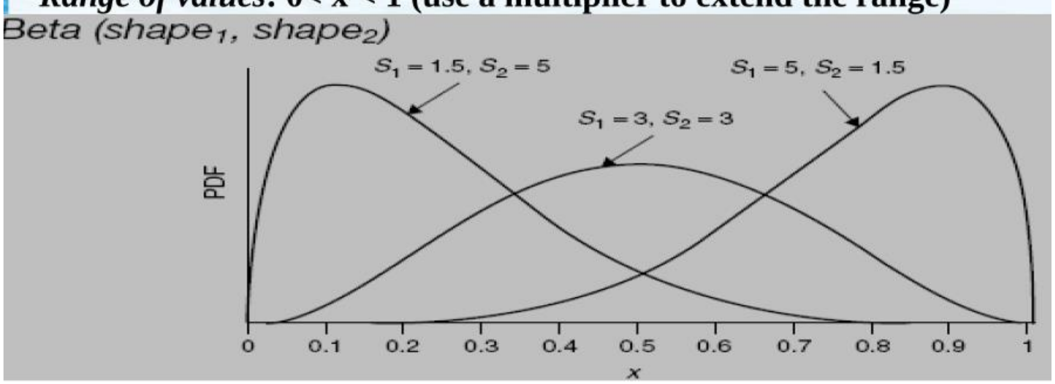
MODELING VARIABILITY:Some common statistical distributions

Beta (Shape$_1$, Shape$_2$): *Potential applications:* time to complete a task; proportions (e.g. defects in a batch of items); useful as an approximation in the absence of data, task times in Pert networks.

***Mean*: (shape$_1$) /(shape$_1$ + shape$_2$)**

***Standard deviation*: $\sqrt{[(shape_1 \times shape_2)/ (shape_1 + shape_2)^2(shape_1 + shape_2 + 1)]}$**

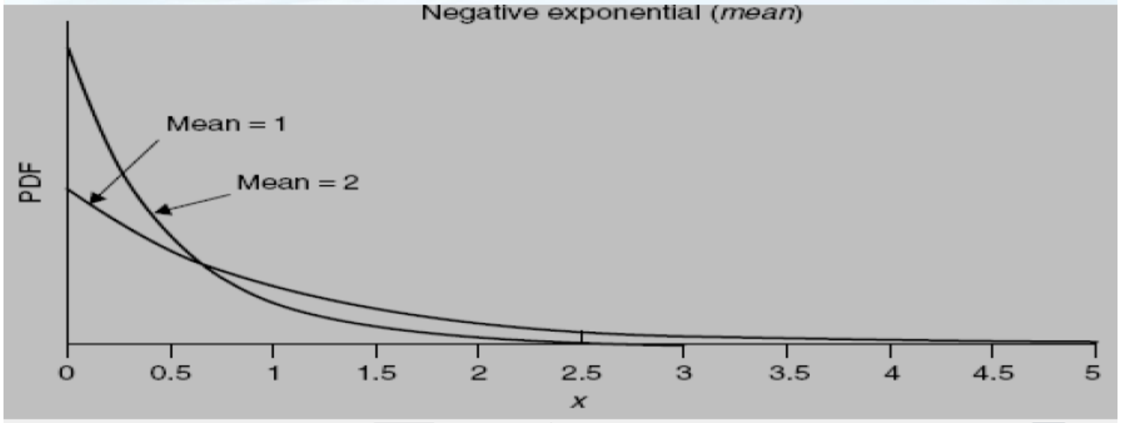
***Range of values*: $0 < x < 1$ (use a multiplier to extend the range)**



MODELING VARIABILITY:Some common statistical distributions

Negative exponential (mean)-exponential distribution

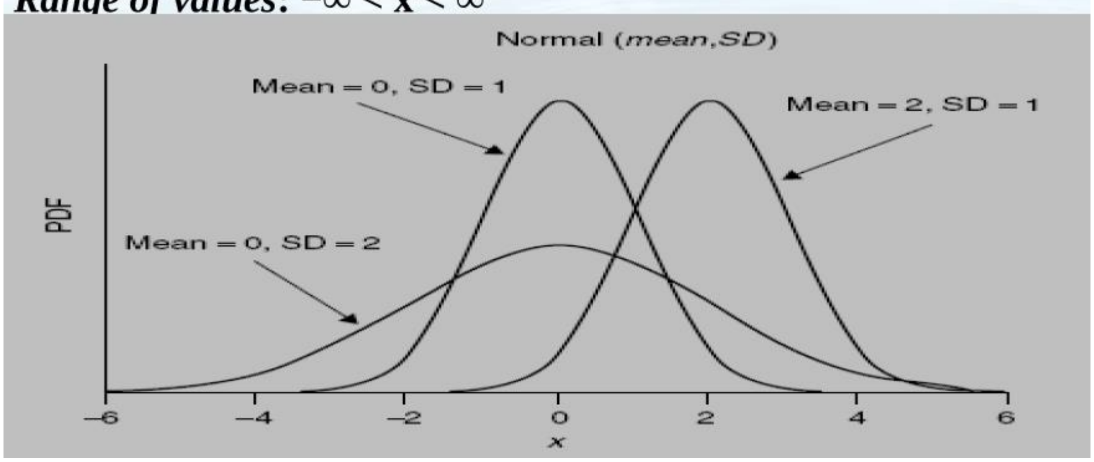
***Potential applications*: inter-arrival times (e.g. customer arrivals, time between failure); time to complete a task;**
***Mean*: mean;**
***Standard deviation*: mean; Range of values: $0 <= x < \infty$**



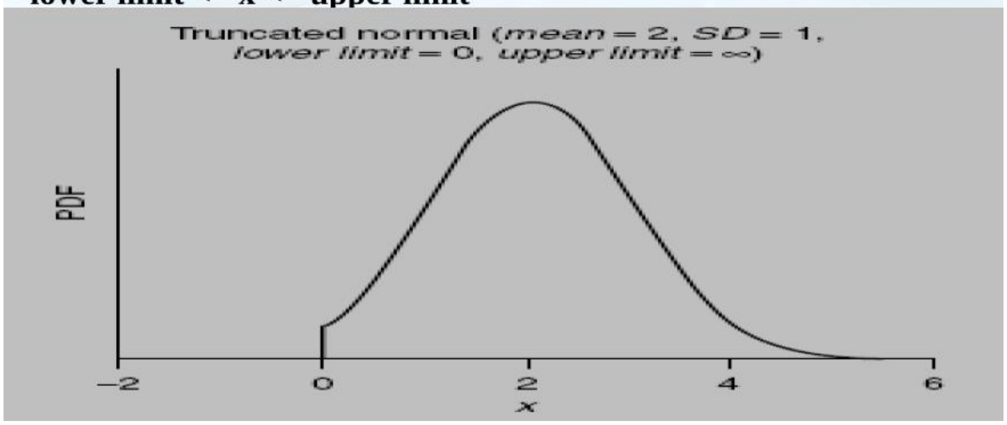
MODELING VARIABILITY:Some common statistical distributions

Normal (mean, standard deviation)

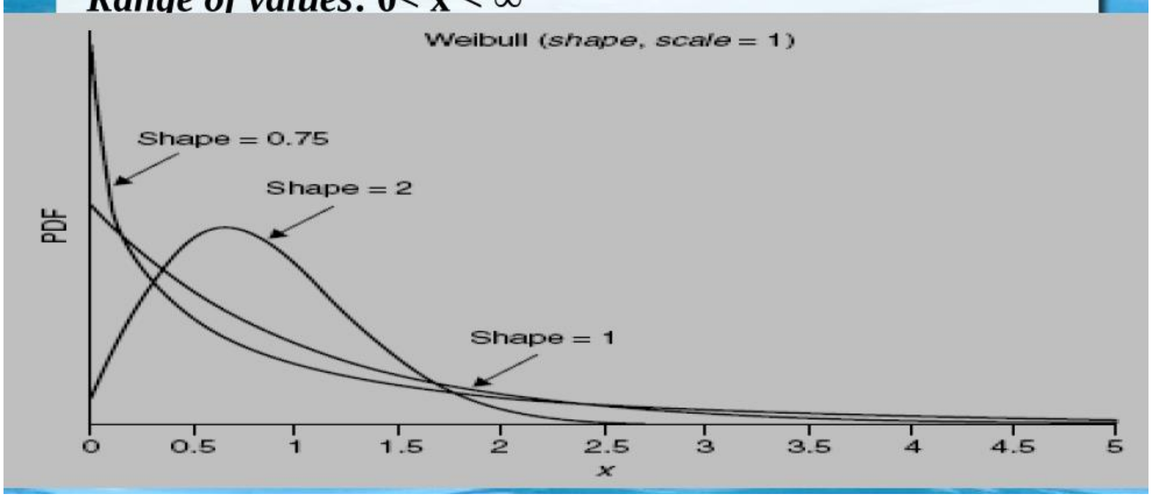
***Potential applications*: errors (e.g. in weight or dimension of components)**
***Mean*: mean; *Standard deviation*: SD;**
***Range of values*: $-\infty < x < \infty$**



Truncated normal (mean, standard deviation, lower limit, upper limit): ***Potential applications*: similar to normal distribution but avoids problem of extreme values (e.g. negative values)**
***Range of values*: if lower limit specified: lower limit <= x < ∞ if upper limit specified: −∞ < x <= upper limit *if both limits specified*: lower limit <= x <= upper limit**



Weibull (shape, scale)
***Potential applications*: time between failure; time to complete a task; model equipment failures;**
***Range of values*: 0< x < ∞**



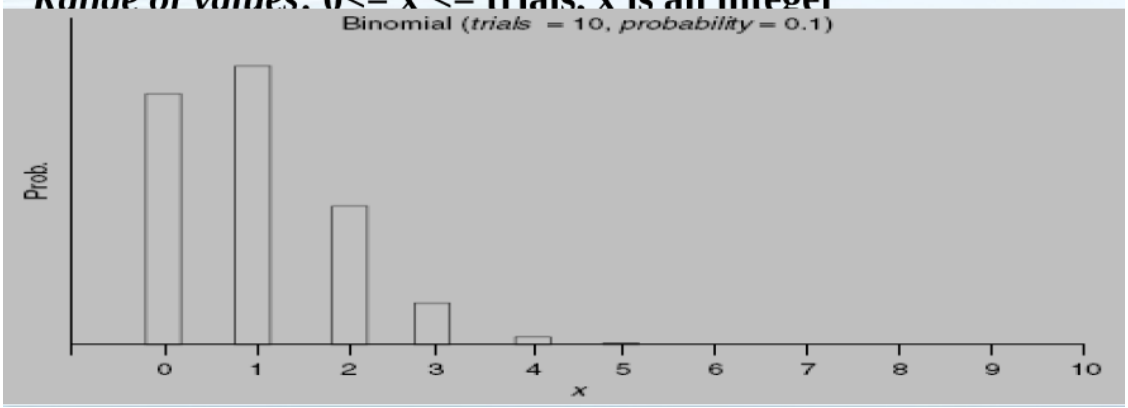
Binomial (trials, probability):

***Potential applications*: total "successes" in a number of trials (e.g. number of defective items in a batch); number of items in a batch (e.g. size of an order)**

***Mean:* trials × probability;**

***Standard deviation*: √(trials × probability (1 − probability))**

***Range of values*: 0<= x <= trials, x is an integer**

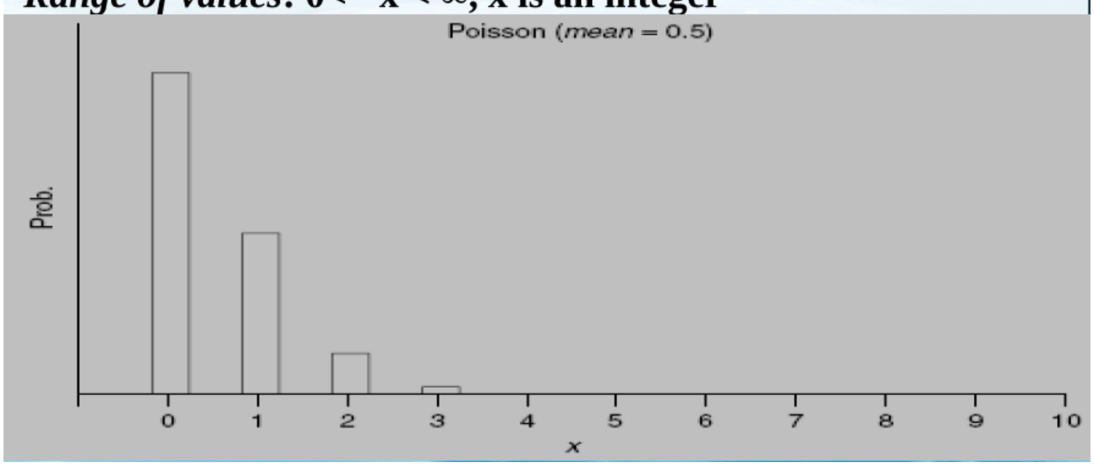


Poisson (mean)

***Potential applications*: number of events in a period of time (e.g. customer arrivals in an hour); number of items in a batch (e.g. size of an order)**

***Mean*: mean; *Standard deviation*: √mean;**

***Range of values*: 0<= x < ∞, x is an integer**



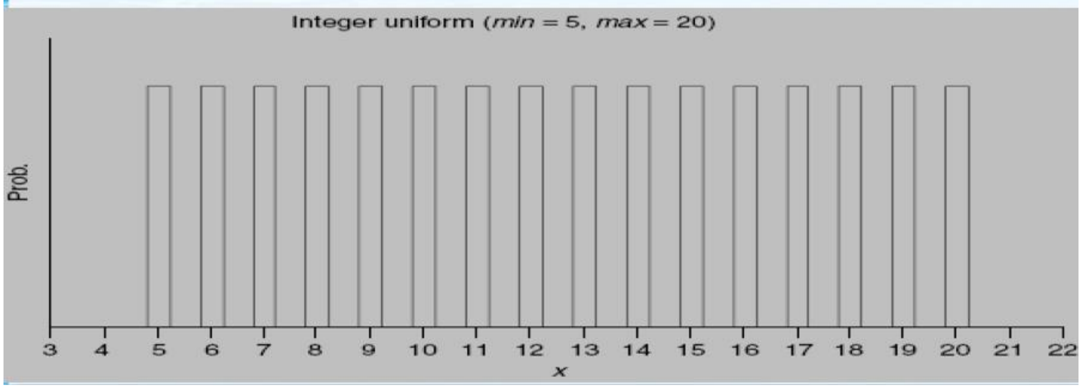
Integer Uniform (min, max)

***Potential applications*: useful as an approximation when little is known other than the likely range of values;**

Mean: (min+max)/2;

***Standard deviation*: $\sqrt{[((max-min+1)^2 - 1)/12]}$;**

***Range*: min <= x <= max, x is an integer**

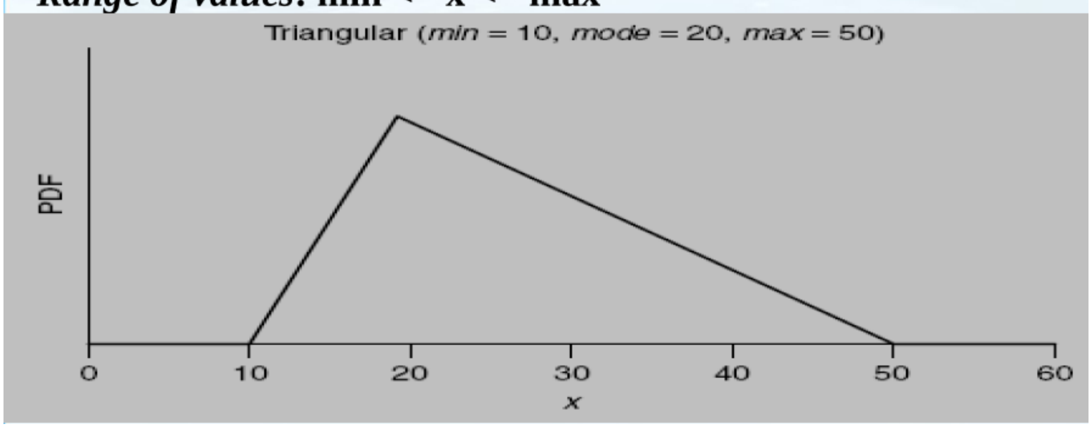


Triangular (min, mode, max)

***Potential applications:* useful as an approximation when little is known other than the likely range of values and the most likely value (mode); *Mean*: (min+mode + max)/3**

***Standard deviation*: $\sqrt{[(min^2 + mode^2 + max^2 - (min \times mode + min \times max + mode \times max)/18]}$;**

***Range of values*: min <= x <= max**



End of Week 1 Exercises

1) Identify and define the important terms in modeling and simulation.
2) Discuss the importance of modeling and simulation as an enterprise.
3) Discuss the domain areas in which simulation is relevant.
4) What is simulation?
5) Why is simulation important and where can it be applied.

More exercises

1. Discuss why simulation may be necessary.
2. Discuss advantages of simulation.
3. Discuss how simulation may be having advantages over other problem solving approaches.
4. Discuss when it may be necessary to use simulation.
5. Describe the three phase approach of discrete event simulation.
6. Discuss how time may be managed in simulation.
7. Show how variability may be handled in simulation.
8. Discuss how random numbers may be generated by hand (top of hat) and by a computer.
9. Discuss how distributions may be used as sources of random numbers.
10. Discuss other useful distributions in simulations.